

Role of Detailed 3-D Cloud Simulations

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NASA Advanced Supercomputing Division

High Ice Water Content
Requirements Definition Review
13 February 2009

Role of Detailed 3-D Cloud Simulations

- use unique field measurements to constrain simulations
 - penetration of high ice water content regions
 - with instruments designed for such conditions
- gain theoretical understanding of microphysics in deep convection
 - how does ice form?
 - what leads to high ice water content with low reflectivity?
- integrate multiple data sources within theoretically consistent context
 - airborne, satellite, and 3-D radar data
- use simulations to extend airborne statistics
 - dependence of average TWC on flight distance

Model Description

- fluid dynamics and radiative transfer
 - large-eddy simulation [*Stevens and Bretherton, 1997*]
 - open or closed lateral boundary conditions
 - order 10 m resolution for shallow convection, 100-1000 m for deep
 - dynamic Smagorinsky subgrid model [*Kirkpatrick et al., 2006*]
 - 2-stream radiative transfer, 44 wavelength bands [*Toon et al., 1989*]
- cloud microphysics
 - size-resolved aerosols, water drops, and ice crystals [*Jensen et al., 1994; Ackerman et al., 1995*]
 - drop activation, condensation/evaporation, sedimentation
 - gravitational collection [*Hall, 1980; Beard and Ochs, 1984*]
 - heterogeneous ice formation with phoretic scavenging [*Young, 1974*] of 0.5- μm -diameter prognostic ice nuclei [*Rogers et al., 2001*]
 - deposition/sublimation and riming
 - ice multiplication: Hallet-Mossop rime splintering, shattering of freezing drops, and ice-ice collision-induced fragmentation

Microphysical Processes

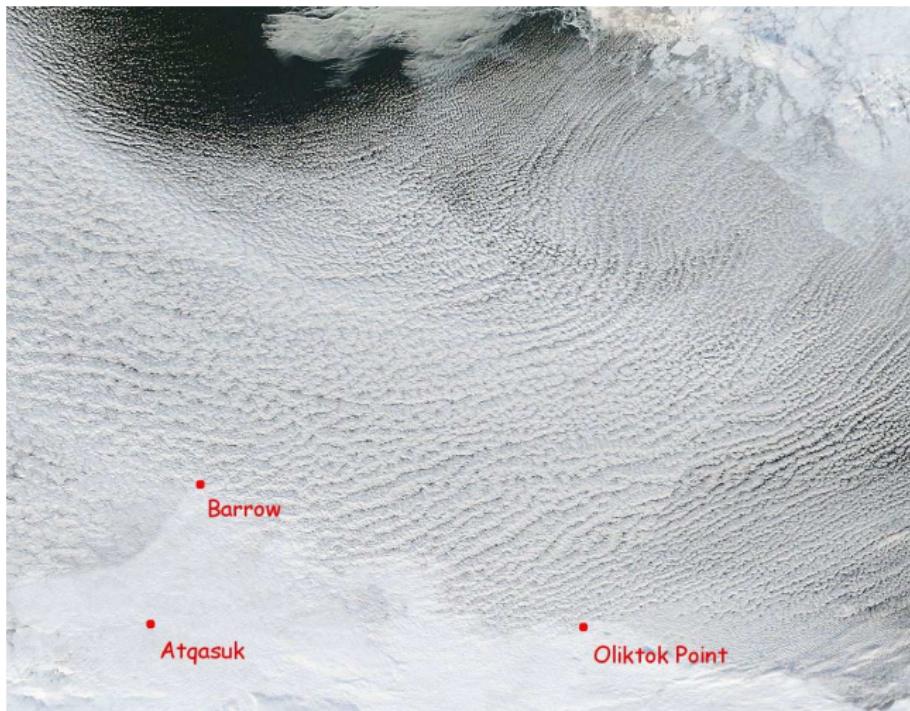
- drop formation (condensation, evaporation)
- gravitational collection (collision, coalescence)
- sedimentation
- homogeneous ice formation ($T < -38^{\circ}C$)
- heterogeneous ice formation ($T > -38^{\circ}C$)

Mechanism	Temp, C	Supersat	Dependence	Description
Primary modes				
contact	$-4 > T > -14$	—	$f_{lin}(T)$	$IN_{aer} + \text{drop} \rightarrow \text{ice}$
condensation	$-8 > T > -22$	$0 < S_w$	$f_{lin}(T)$	$IN_{aer} + \text{vapor} \rightarrow \text{ice}$
deposition	$-10 > T$	$0 < S_i < 0.2$	$f_{exp}(S)$	$IN_{aer} + \text{vapor} \rightarrow \text{ice}$
immersion	$-10 > T > -24$	—	$f_{lin}(T)$	$\text{drop} + IN_{drop} \rightarrow \text{ice}$



2004 Mixed-Phase Arctic Cloud Experiment (M-PACE)

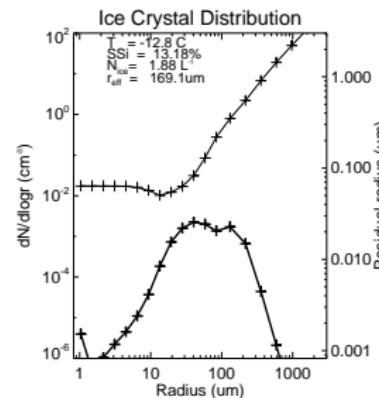
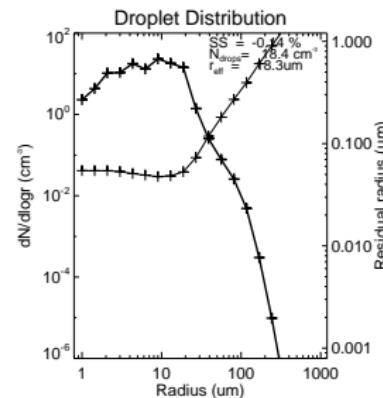
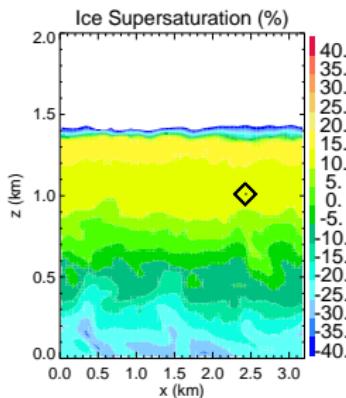
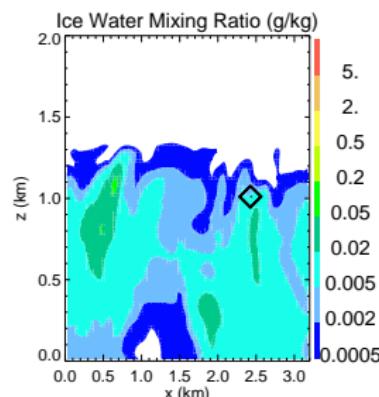
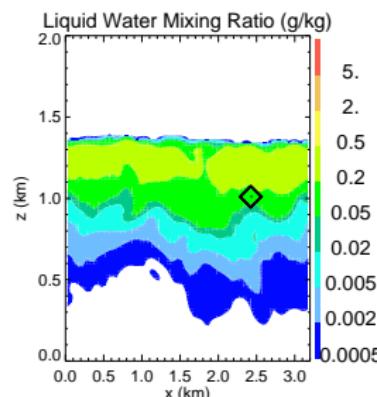
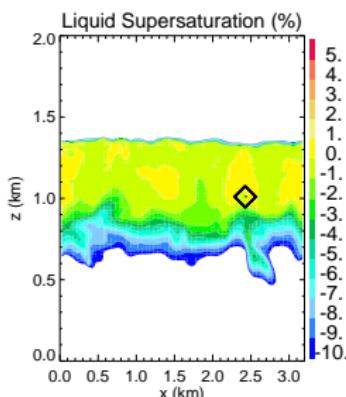
Barrow, Alaska



Source: AVHRR, image courtesy of Hans Verlinde and Jerry Harrington, Pennsylvania State University

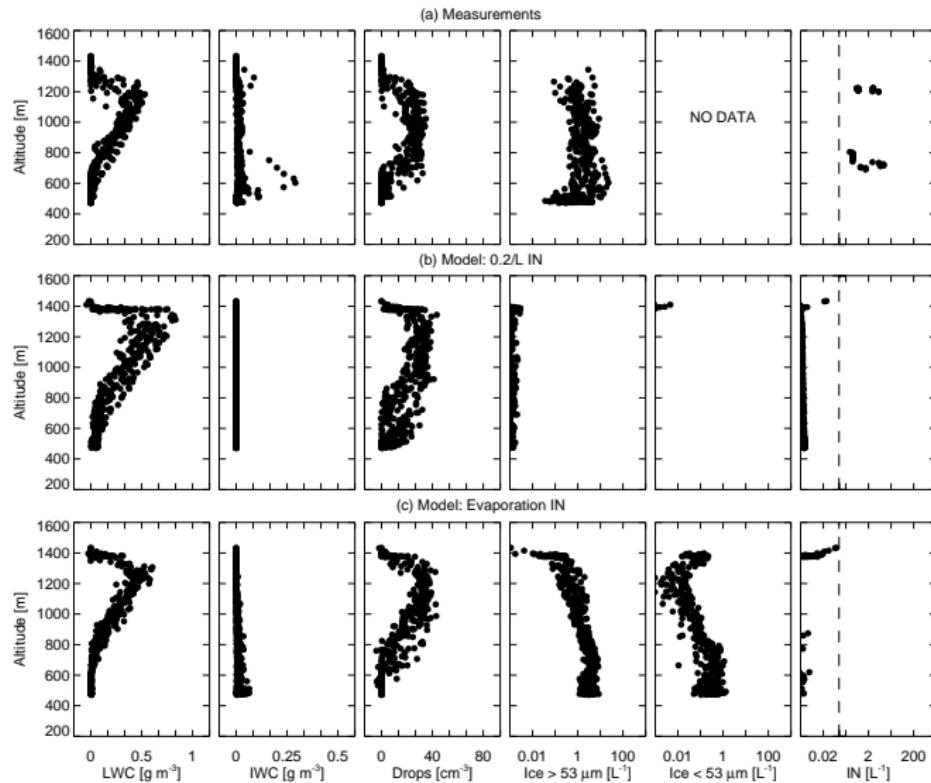
2004 Mixed-Phase Arctic Cloud Experiment (M-PACE)

Slice of Model Results



2004 Mixed-Phase Arctic Cloud Experiment (M-PACE)

Flight Data vs Model Results



Source: Fridlind et al., JGR, 2007

Hypothesized Ice Formation Mechanisms

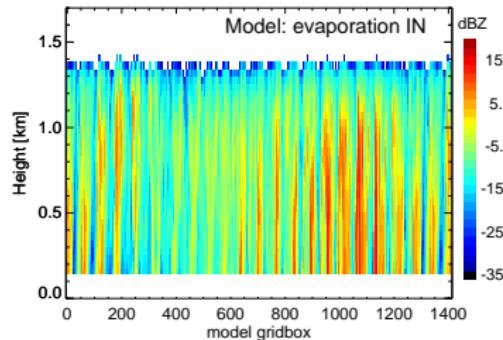
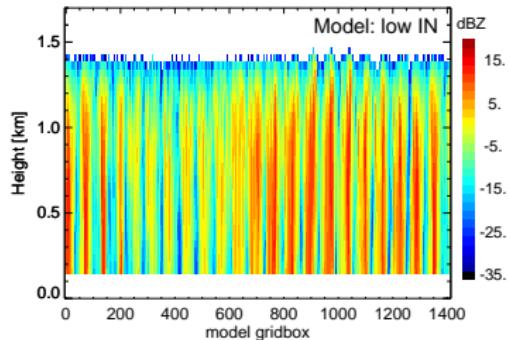
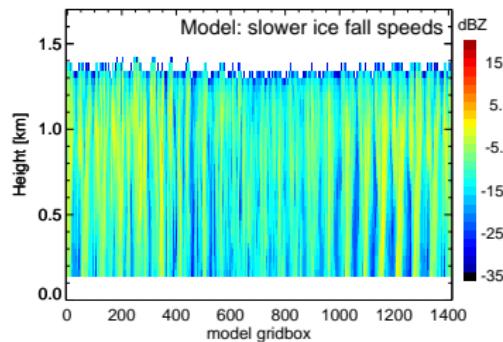
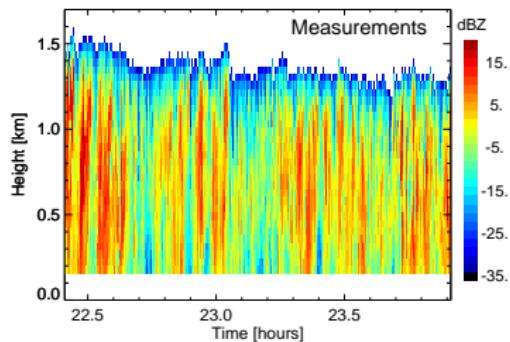
- evaporation nuclei [*Beard, 1992*]
 - according to Langer et al. [*1979*], first suggested by Georgii [*1959*]
 - one in $10^4\text{--}10^5$ drop residuals [*Rosinski and Morgan, 1991*]



- evaporation freezing
 - ice nucleation during drop evaporation [*Cotton and Field, 2002*]
 - as via organic films [*Cantrell and Robinson, 2006*]

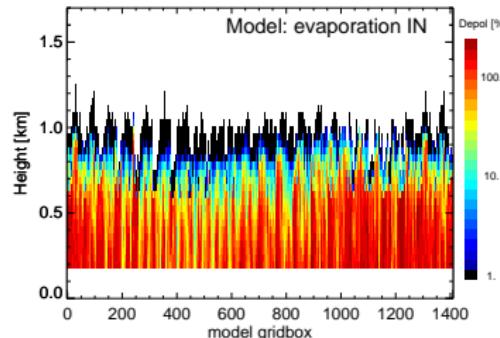
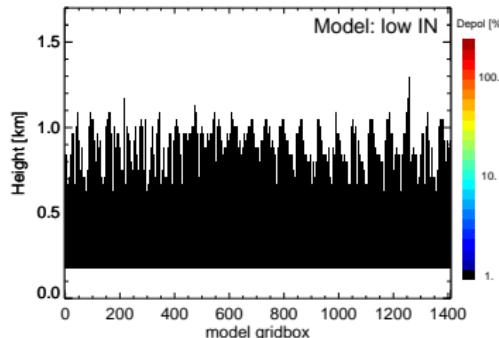
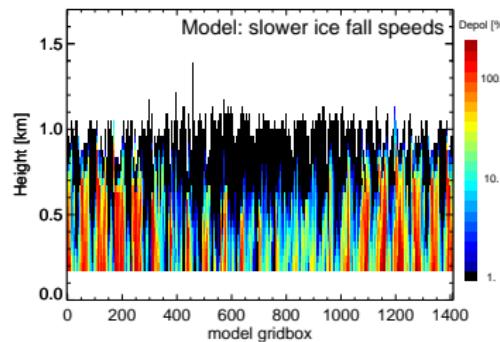
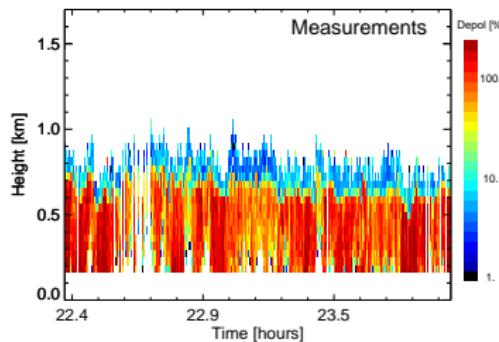


Cloud Radar Measurements and Simulations



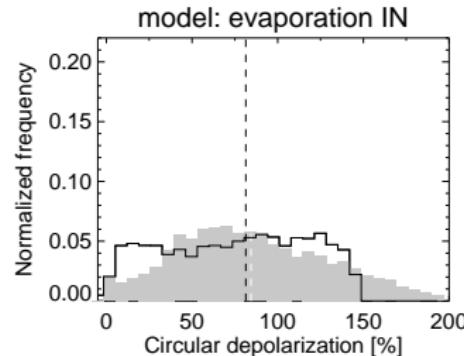
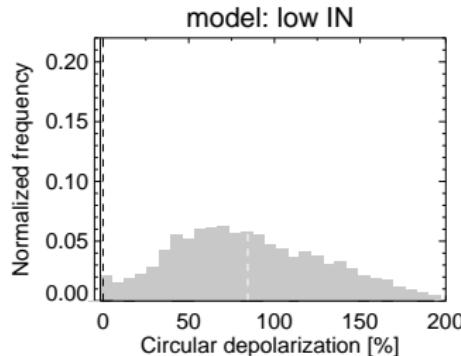
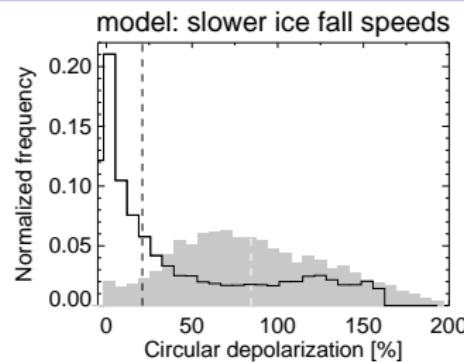
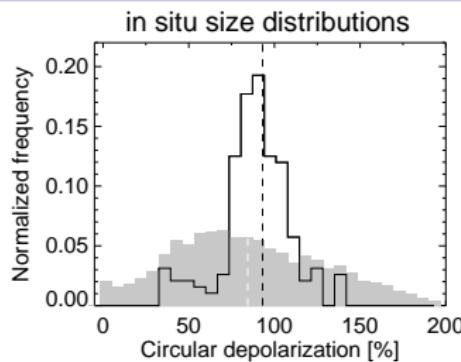
Source: *van Diedenhoven et al., JGR, provisionally accepted*

Lidar Measurements and Simulations



Source: *van Diedenhoven et al., JGR, provisionally accepted*

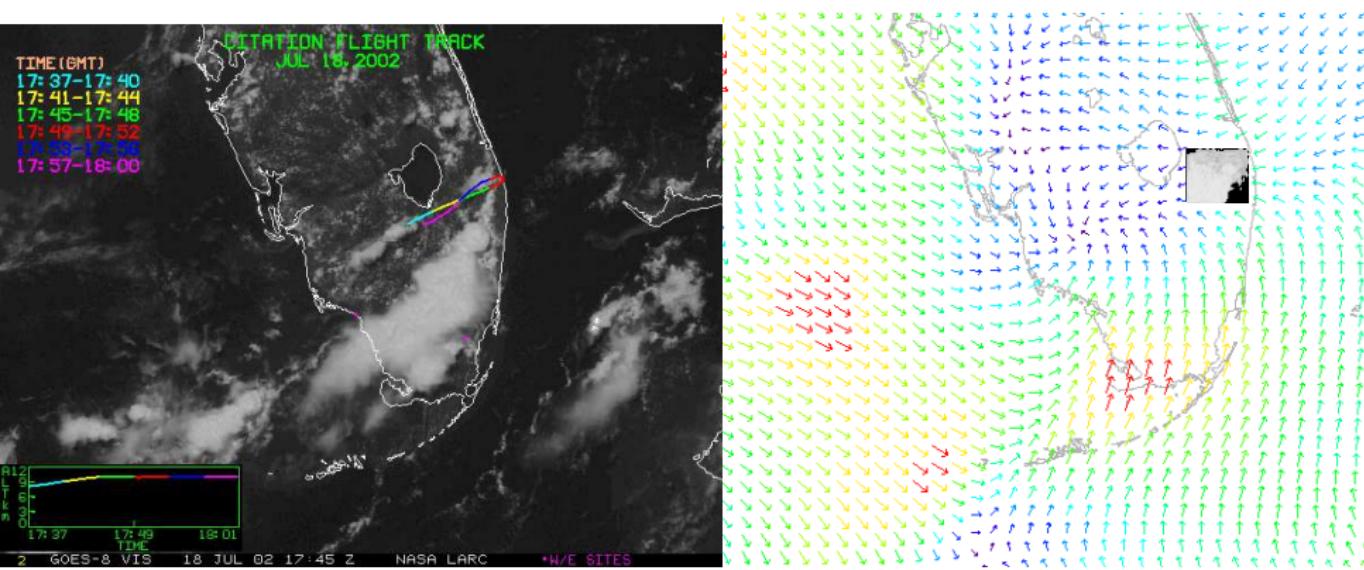
Lidar Measurements and Simulations



Source: van Diedenhoven et al., JGR, provisionally accepted

2002 CRYSTAL-FACE Field Experiment

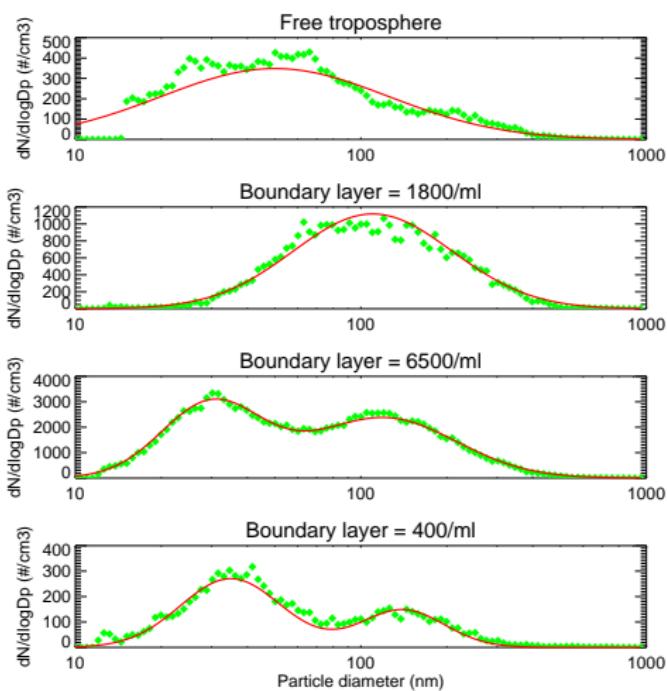
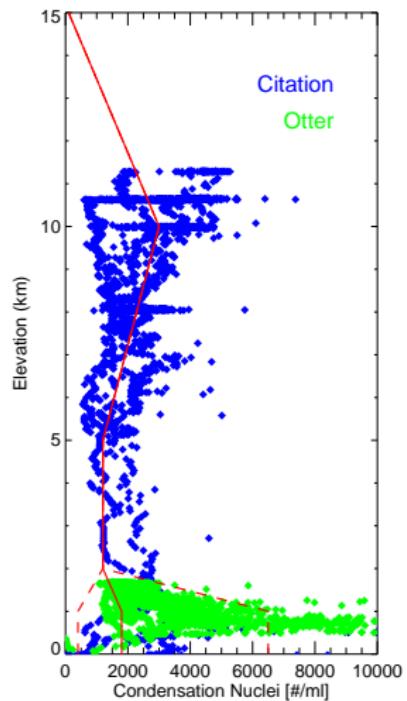
Southern Florida



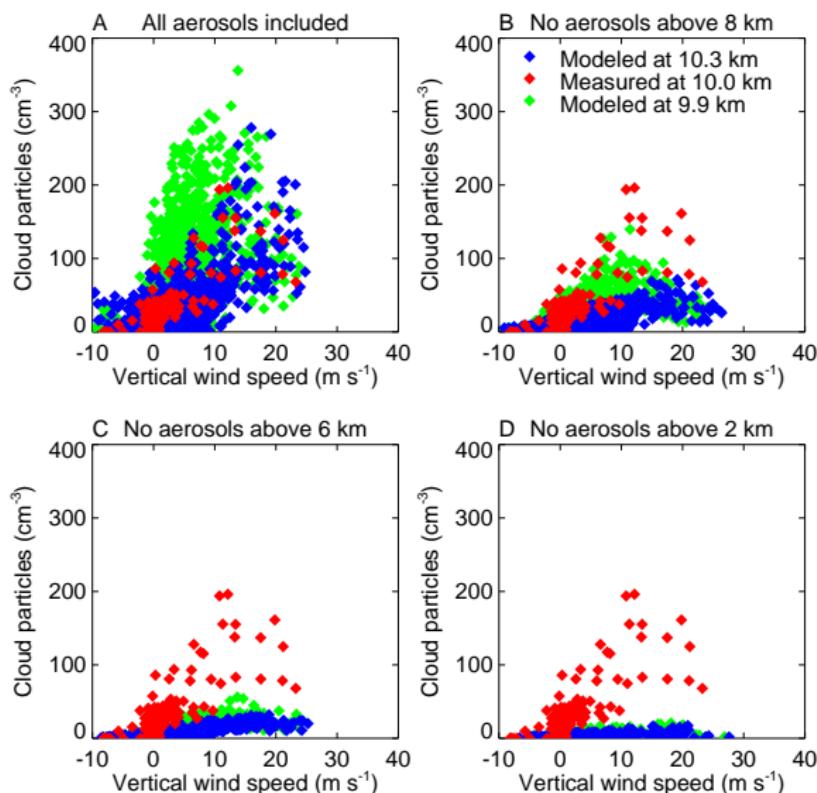
Source: Fridlind et al., Science, 2004

2002 CRYSTAL-FACE Field Experiment

Aerosol Number Size Distributions

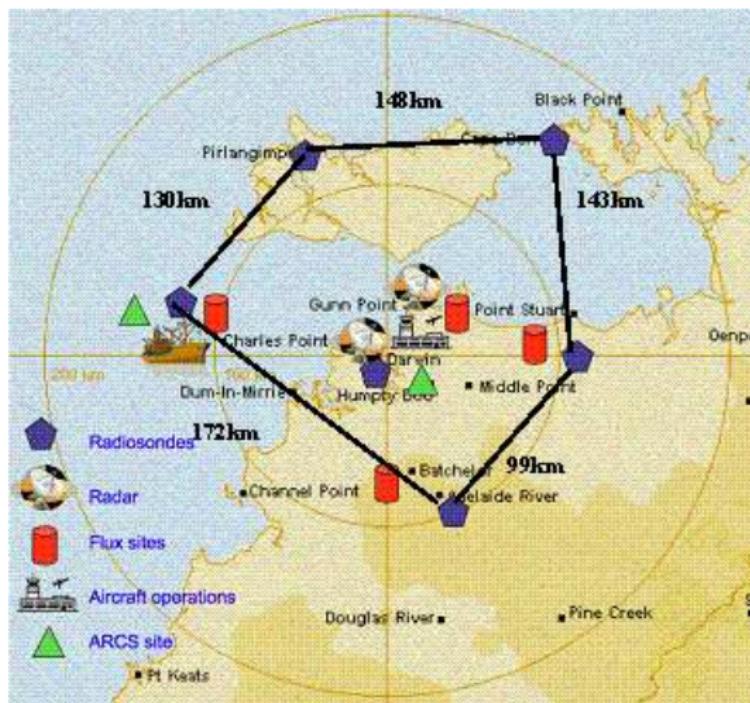


Cloud Particle Concentrations in a 25-m/s Updraft



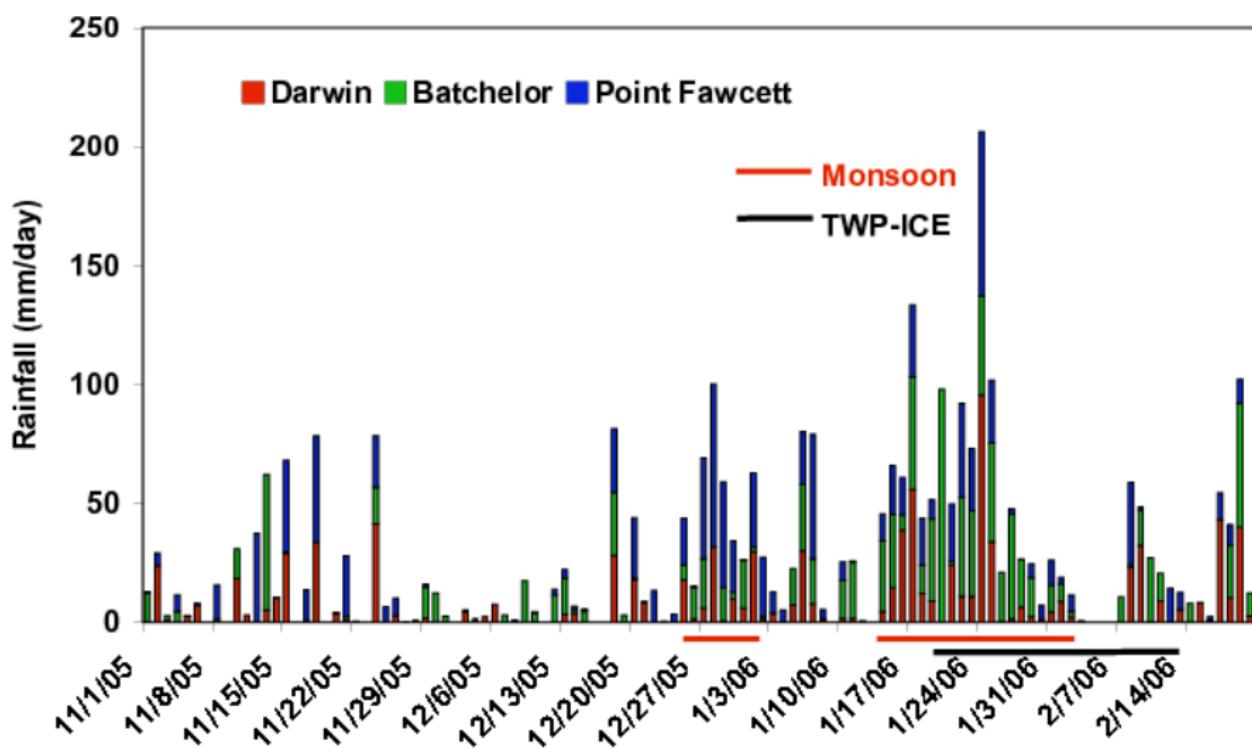
2006 Tropical Warm Pool—International Cloud Experiment (TWP-ICE)

Darwin, Australia



2006 Tropical Warm Pool—International Cloud Experiment (TWP-ICE)

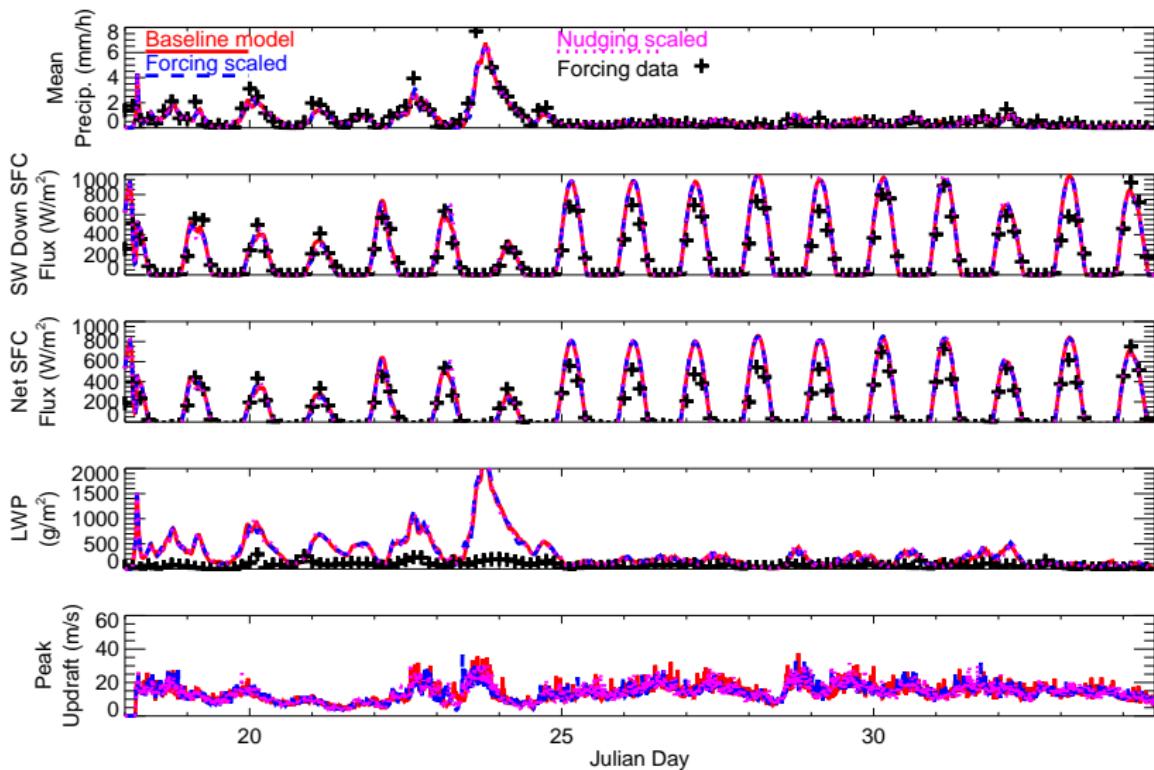
2005/2006 Wet Season



Source: Lori Chappel / Australian BOM

2006 Tropical Warm Pool—International Cloud Experiment (TWP-ICE)

Measured and Simulated Time Series

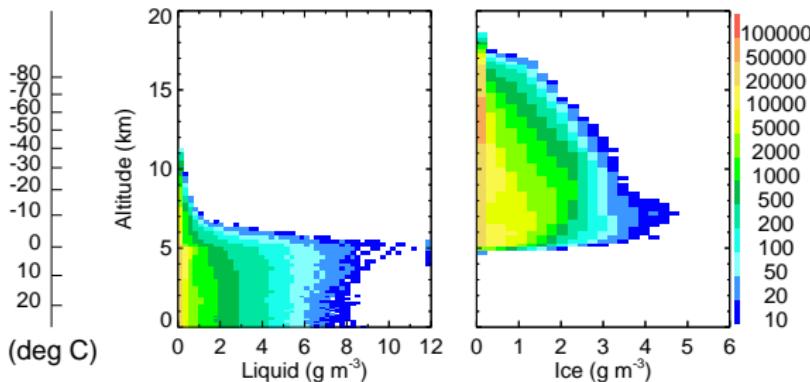
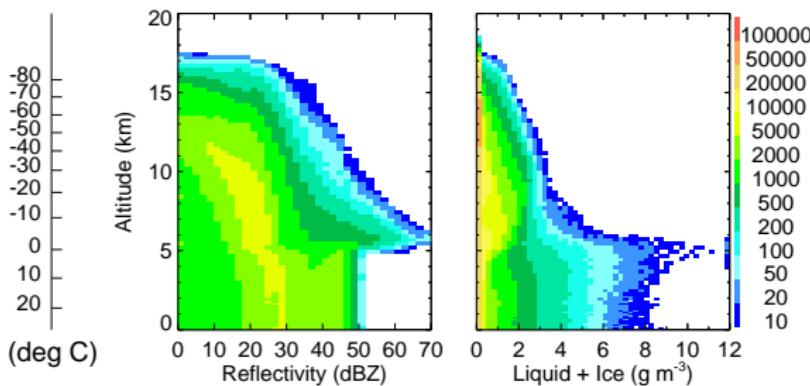


Source: *Forcing data set courtesy Shaocheng Xie and Steve Klein*

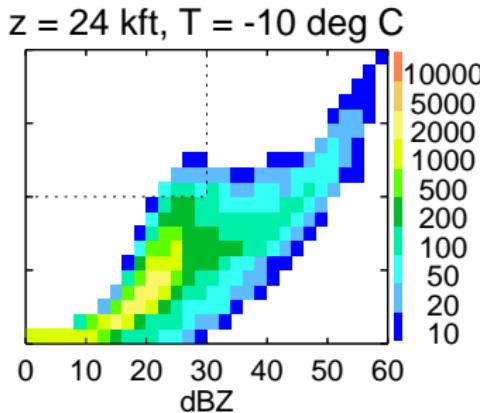
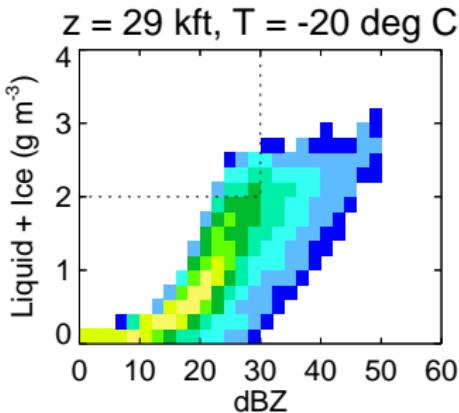
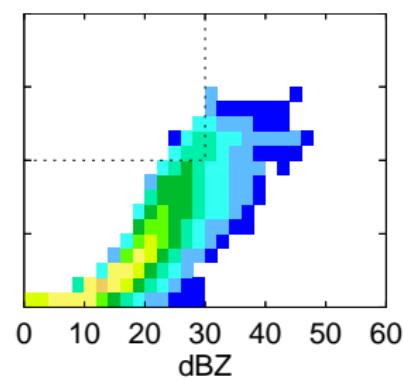
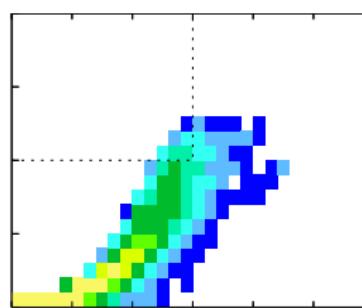
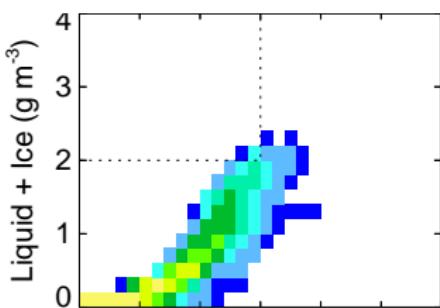
Simulated Total Water Content Isosurfaces

VIEW MOVIE

Simulated Total Water Content Distribution

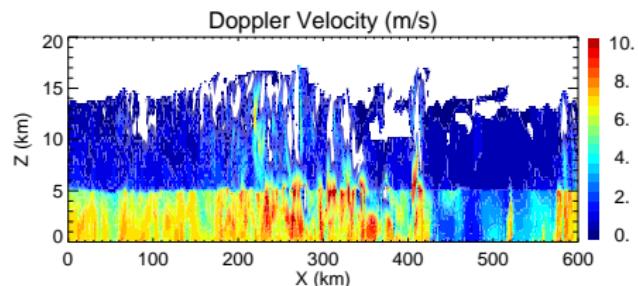
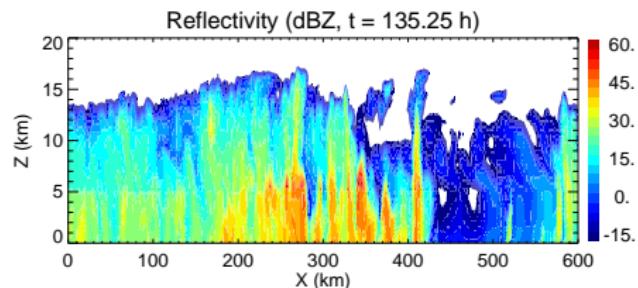
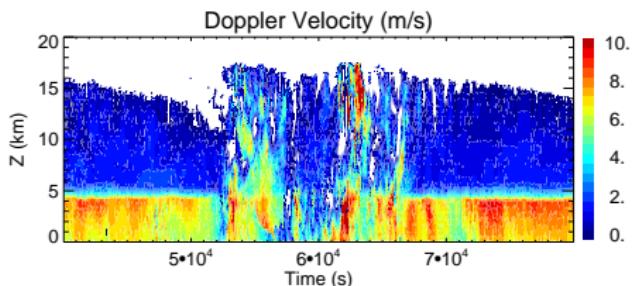
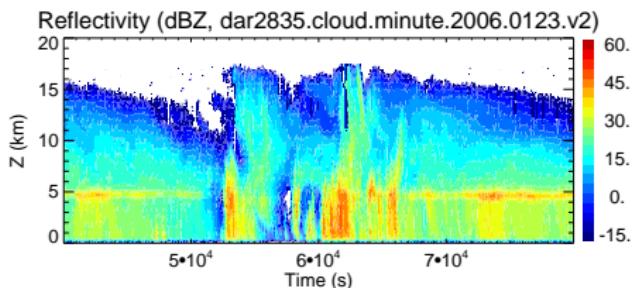


Simulated TWC and Radar Reflectivity



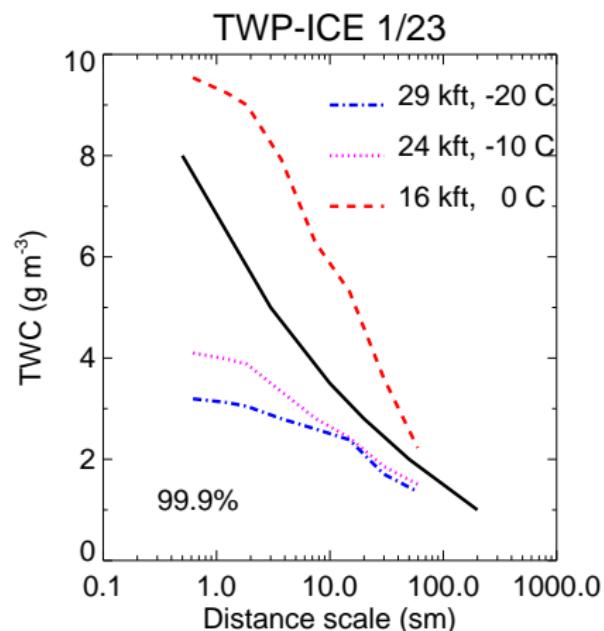
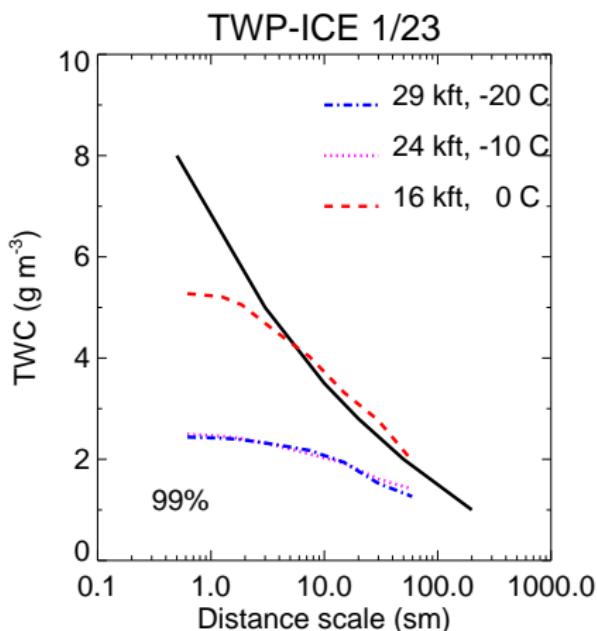
2006 Tropical Warm Pool—International Cloud Experiment (TWP-ICE)

Measured and Simulated Doppler Radar Reflectivity



Source: Christopher Williams (NOAA), DOE ARM data archive

Prospective Use of Simulations to Extend Statistics



Source: *Table A-1 TWC guidelines (black line)*

Role of Detailed 3-D Cloud Simulations

Summary

- roles in this campaign
 - exploitation of existing TWP-ICE simulations and field measurements
 - valuable model constraints expected from probing convective storm cores
 - prospective use of simulations to extend airborne statistics
- modeling approach
 - interplay of microphysics and dynamics recommends coupled approach
 - size-resolved microphysics approach useful when size distributions matter
- related activities
 - study of ice formation in arctic stratocumulus
 - TWP-ICE international CRM modeling intercomparison
 - use of ground-based and satellite remote-sensing and in situ measurements